Matter AntiMatter Fluctuations

Search, discovery & analysis of Bs oscillations

N. Leonardo

CERN Library, 15/9/2011

outline

- about the discovery
- about the monograph
- about the physics
  - antimatter and particle mixing
  - selected results
- analogies with an ongoing search
- Q&A

thanks to CERN Library, especially Tullio Basaglia, Jens Vigen, for the invitation

book presentation

Matter Antimatter Fluctuations

search, discovery and analysis of Bs flavor oscillations

Lambert Publishing (2011)
ISBN: 9783843376938

about the author

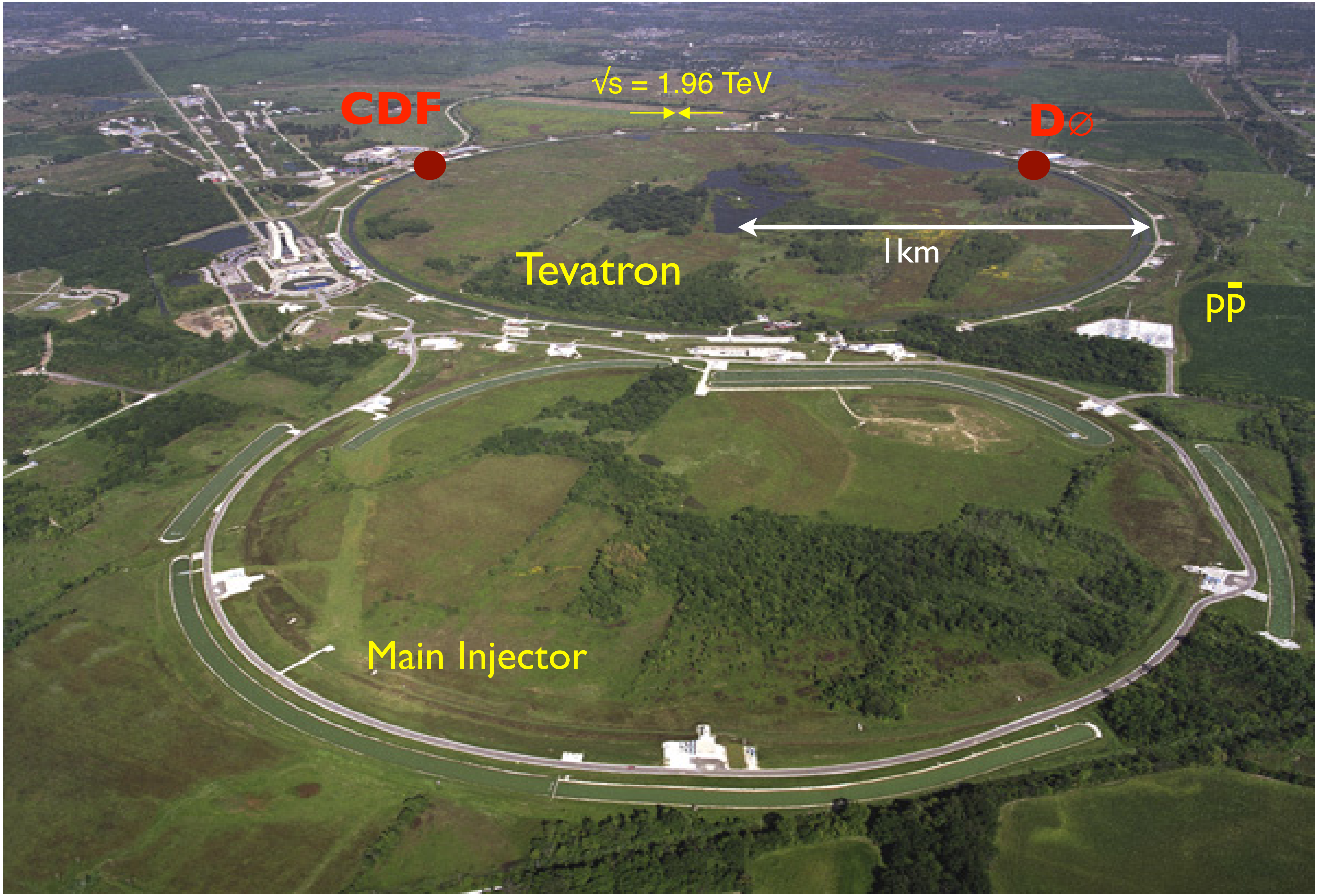
- particle physicist, currently working at LHC's CMS
- first came to CERN 14 years ago as a summer student
  - enjoyed the stay ➠ decided to pursue career in the field
- moved to grad school: Cambridge, UK and then Cambridge, MA
- thesis research (book's subject) at Fermilab, near Chicago
- returned to CERN, as research fellow, 5 years ago this month
- continued since based at CERN as researcher in CMS

the discovery

- book based on research performed in CDF experiment @ Fermilab
- Tevatron
  - highest energy accelerator at time of research, and until LHC turn-on in 2010
  - termination of beam operations in two weeks (2011/9/30 2:00pm CDT)
- measurement: Search & observation of Bs flavor oscillations
  - closed book on a two-decade quest
- considered to be a flagship analysis of the Tevatron physics program
- arguably most complex measurement performed at a hadron collider
  - reason: composed of many analyses, and multiple signals combined (sensitivity)
- this month: final measurement becomes 5 years old (started 10 years)

Tevatron Collider (1985-2011)

@Fermilab



History *a 20 year quest*

1987

- first evidence of B^0 mixing by UA1 — PLB 186, 247 (1987)
- followed by observation of B^0 mixing by Argus — PLB 192, 245 (1987)

1989

- CLEO confirms Argus results — PRL 62, 2233 (1989)

1990s

- inclusive B mixing measurements from LEP establish B_s mixing

1993

- first time dependent measurements of Δm_d by ALEPH — PLB 313, 498 (1993)
- first lower limit on Δm_s by ALEPH — PLB 322, 441 (1994)

1999

- CDF Run I result on Δm_s: $\Delta m_s > 5.8\ \text{ps}^{-1}$ — PRL 82, 3576 (1999)

2005

- DØ first result Δm_s: $\Delta m_s > 5.0\ \text{ps}^{-1}$
- CDF Run II first results Δm_s: $\Delta m_s > 7.9\ \text{ps}^{-1}$

2006

- DØ reports interval: $\Delta m_s \in [17,21]\ \text{ps}^{-1}$ at 90% CL — PRL 97, 021802 (2006)
- CDF Run II first measurement $\Delta m_s = 17.31^{+0.33}_{-0.18} \pm 0.07\ \text{ps}^{-1}$ — PRL 97, 062003 (2006)
- CDF Run II first observation $\Delta m_s = 17.77 \pm 0.10 \pm 0.07\ \text{ps}^{-1}$ — **PRL 97, 242003 (2006)**

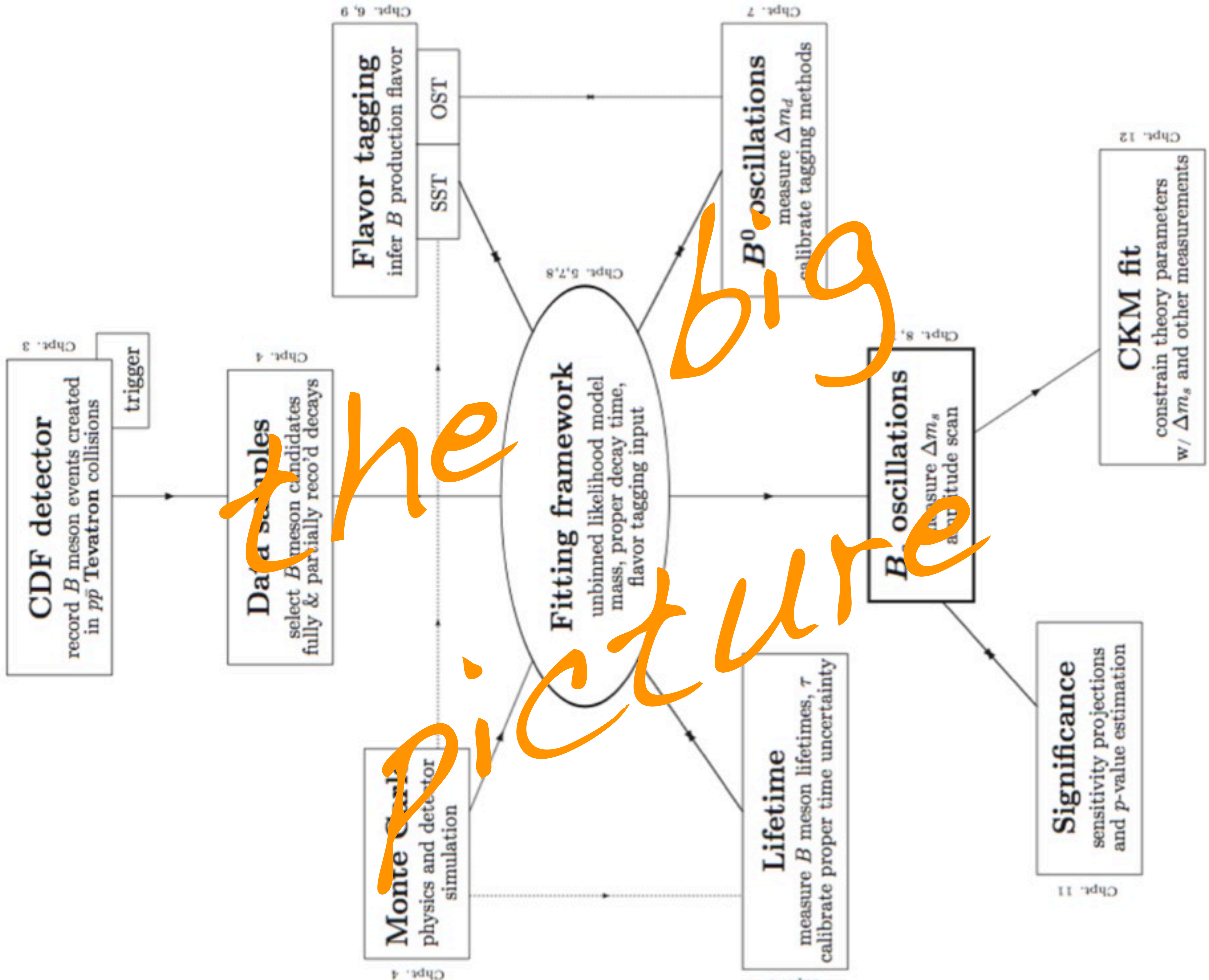
“A Real Flip-Flopper, at 3 Trillion Times a Second”

The New York Times, 18/4/2006

the monograph

- book attempts at providing a complete description of the topic
  - analysis results had been published in two small letters (PRL) in 2006
- detailed description of theory foundation & experimental technique
  - theory motivation ➠ measurement ➠ impact on theory
  - present measurement components as individual analyses, in own right
- starts with roadmap and overview of analysis components
- résumé: brief summary at end of each chapter

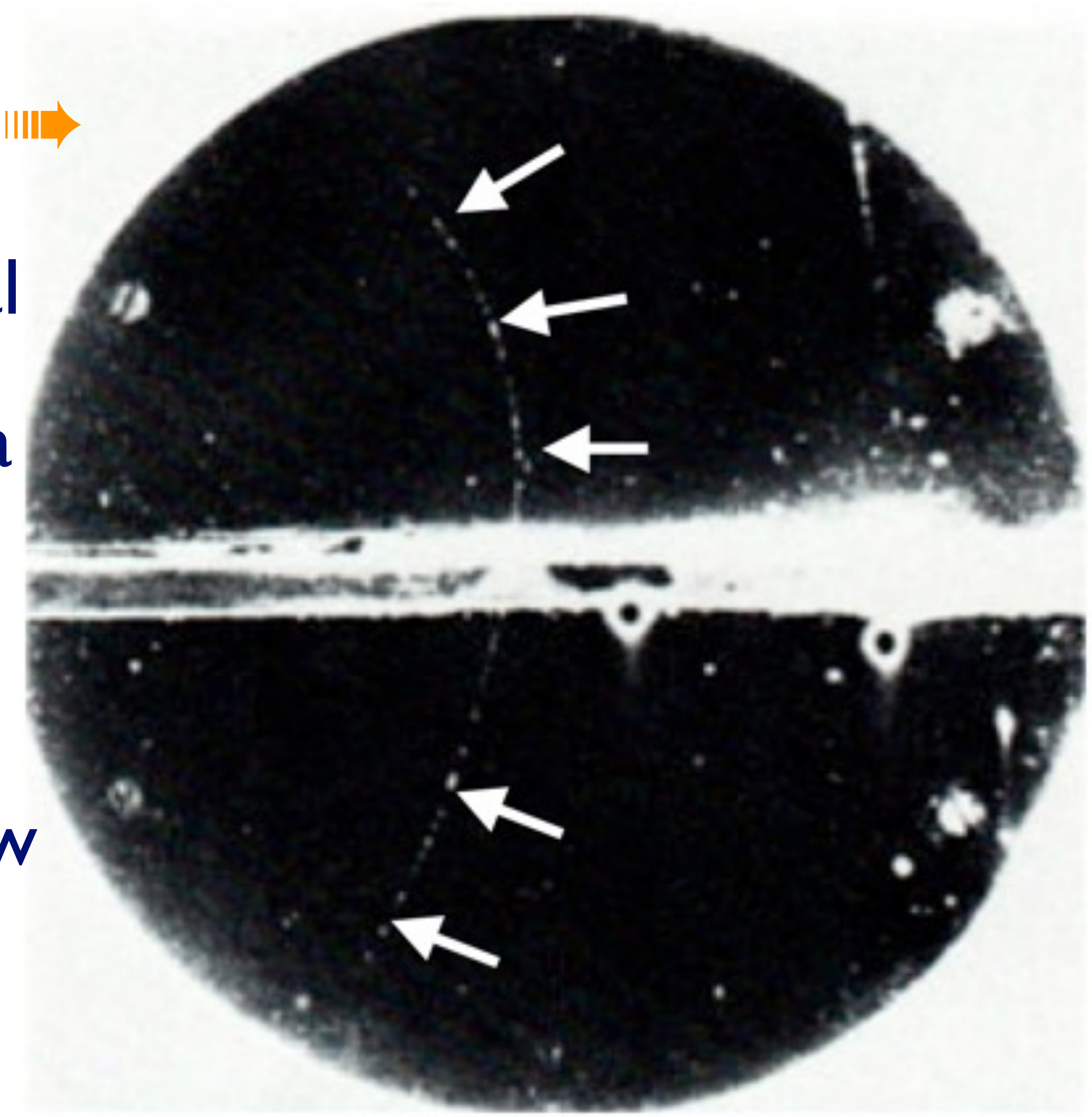
- presents a set of complete measurements ➠ representative of the (B physics) line of research at hadron colliders



the big picture
CDF detector
record B meson events created in $p\bar{p}$ Tevatron collisions
trigger
Chpt. 3
Chpt. 4
select B meson candidates
fully & partially reco'd decays
Flavor tagging
infer B production flavor
SST
OST
Chpt. 6, 9
Fitting framework
unbinned likelihood model
mass, proper decay time,
flavor tagging input
Chpt. 5,7,8
oscillations
measure Δm_d
calibrate tagging methods
Chpt. 7
oscillations
measure Δm_s
amplitude scan
CKM fit
constrain theory parameters
w/ Δm_s and other measurements
Chpt. 12
Significance
sensitivity projections
and p-value estimation
Chpt. 11
Lifetime
measure B meson lifetimes, τ
calibrate proper time uncertainty
Chpt. 5
physics and detector
simulation
Chpt. 4

history of antimatter

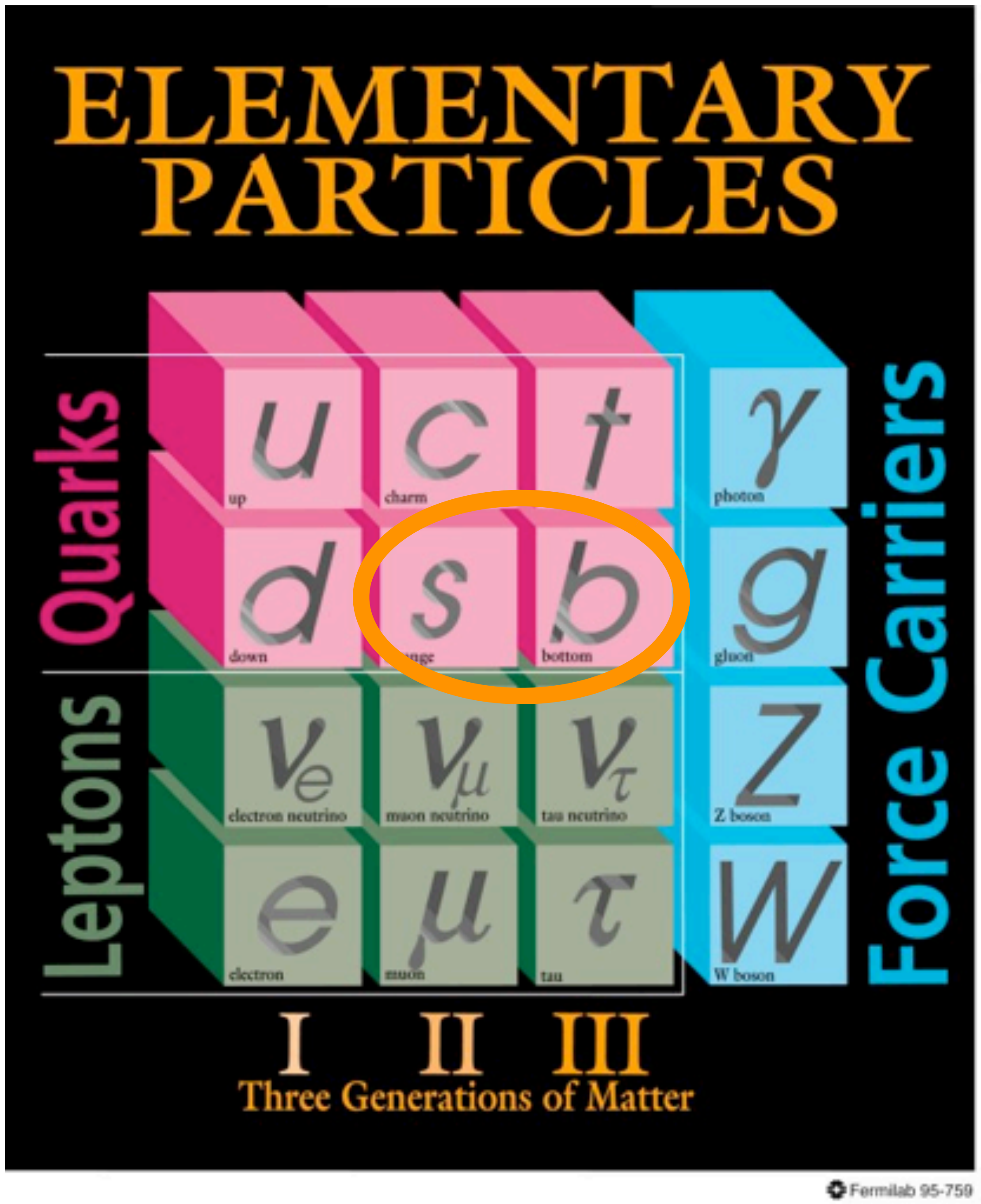
- 1928 Dirac predicts anti-electron
- 1933 Carl Anderson finds the positron
- 1955 anti-proton, Serge, Camberlain, et al
- 1960 anti-neutron by Cork, Piccione, et a
- 1965 anti-deuteron by Lederman et al (BNL) and Zichichi et al (CERN)
- anti-particles of most particles found now
- 1995 anti-hydrogen produced at CERN
- 1999 activation of CERN's AD
- 6 months ago ALPHA trapped 309 anti-hydrogen atoms, for as long as ~17 minutes
- next: ELENA (100 keV antiproton source)



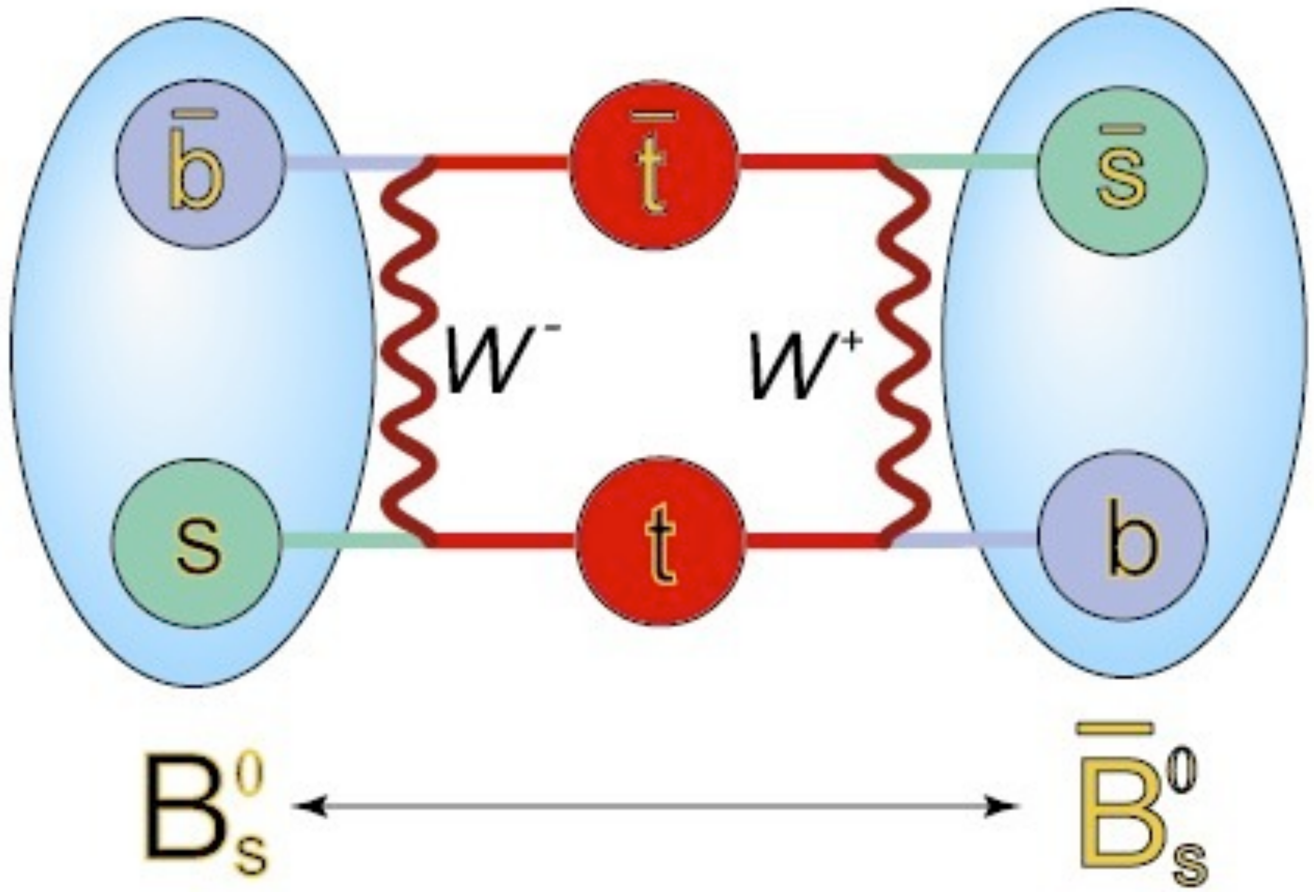
antiparticles have same properties as particles but opposite charges

neutral particle mixing

- ‘flavor’ mixing is a quantum mechanical effect (frequency~Δm)
  - flavor and mass eigenstates differ
  - Bs (b̲s)
  - B0 (b̲d)
  - D0 (u̲c)
  - K0 (ds)
  - N (udd)
  - ν
  - t (decays before hadronizing)
  - π0, Z, γ,... (eg particle=antiparticle)
- charged particles cannot mix
  - electric charge protected by gauge, thus exact, symmetry



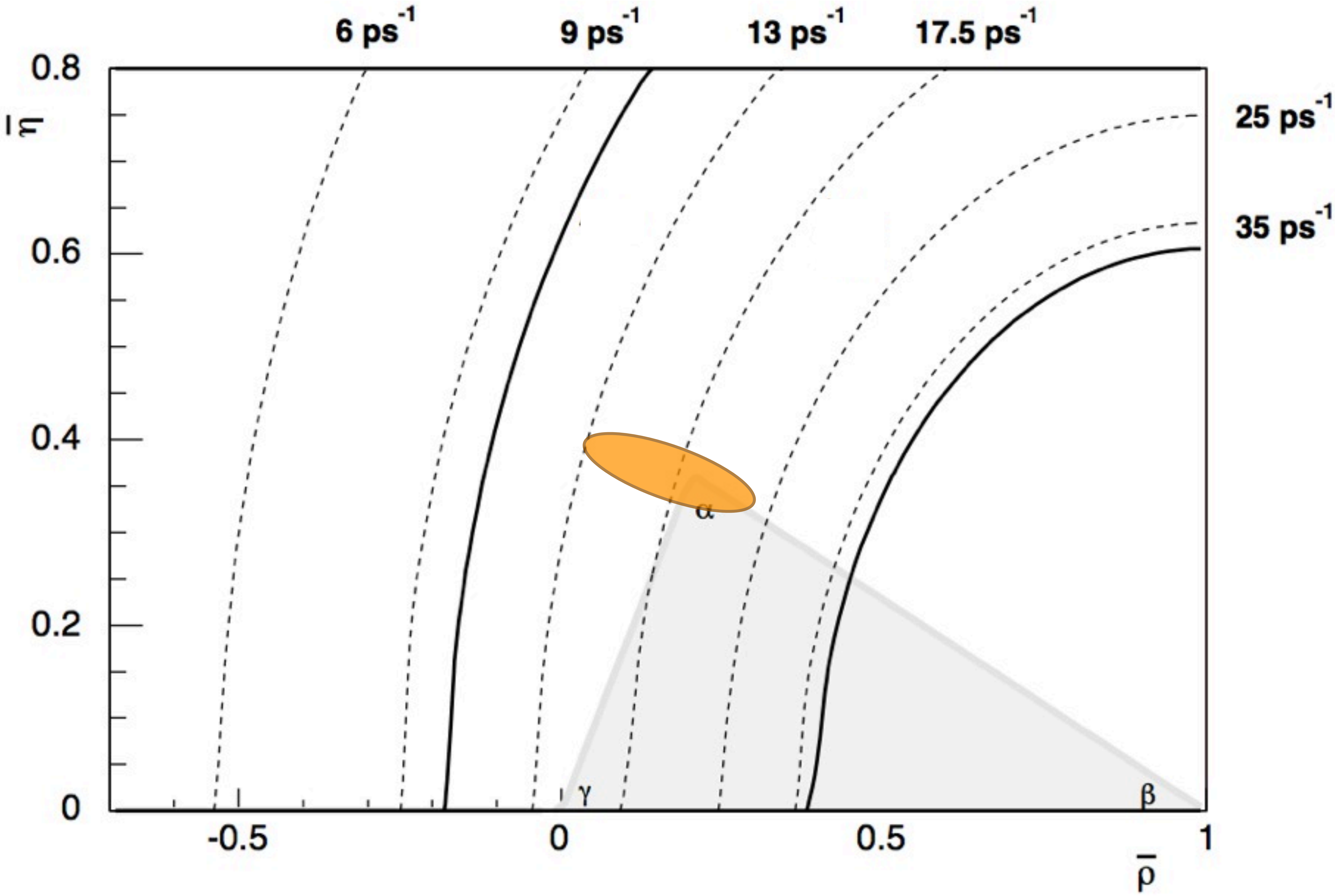
How Bs meson oscillates



Standard Model, via weak interaction, *effectively*: b↔s

New Physics particles may participate in the loop, too

oscillation frequency vs SM



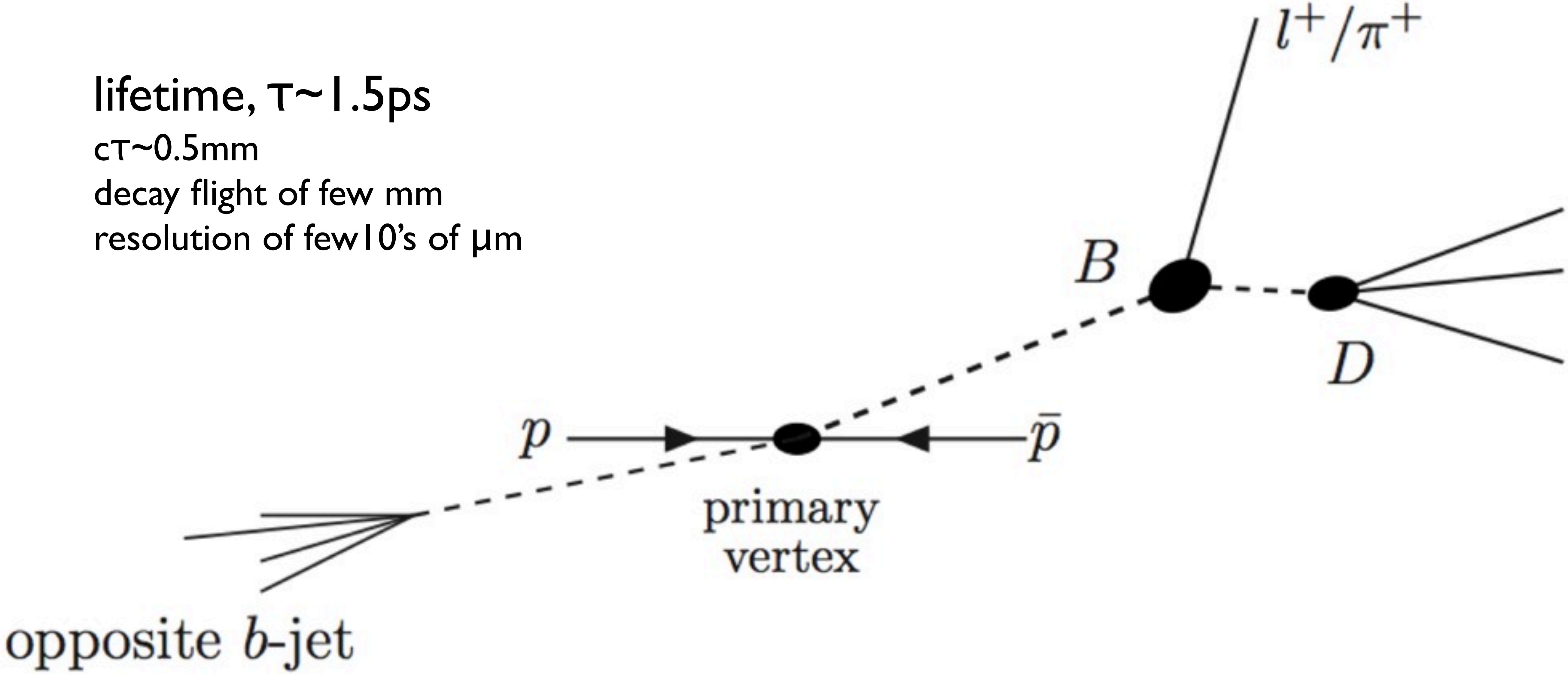
B meson event

lifetime, τ~1.5ps

cτ~0.5mm

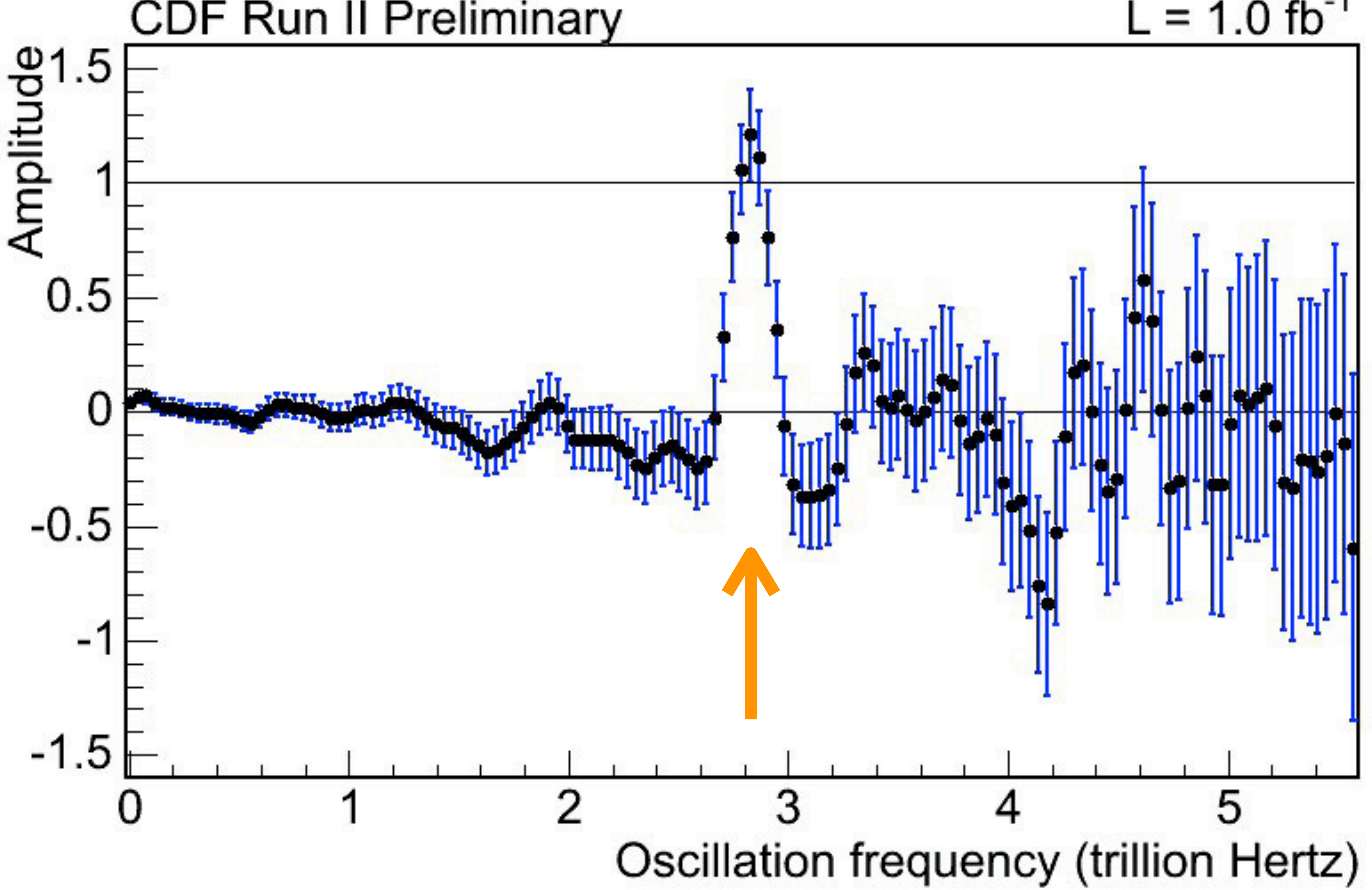
decay flight of few mm

resolution of few10's of μm

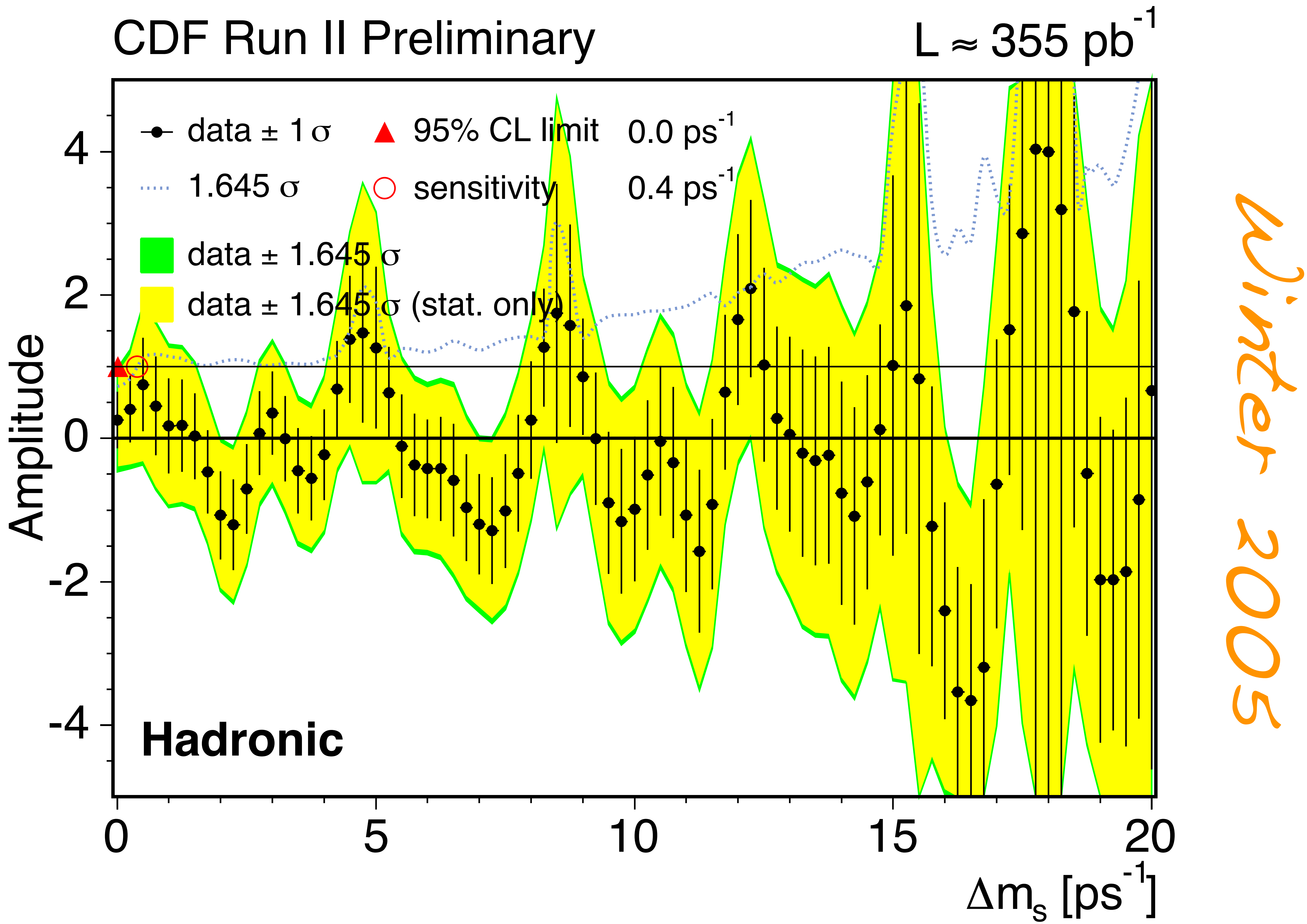


measurement ingredients:

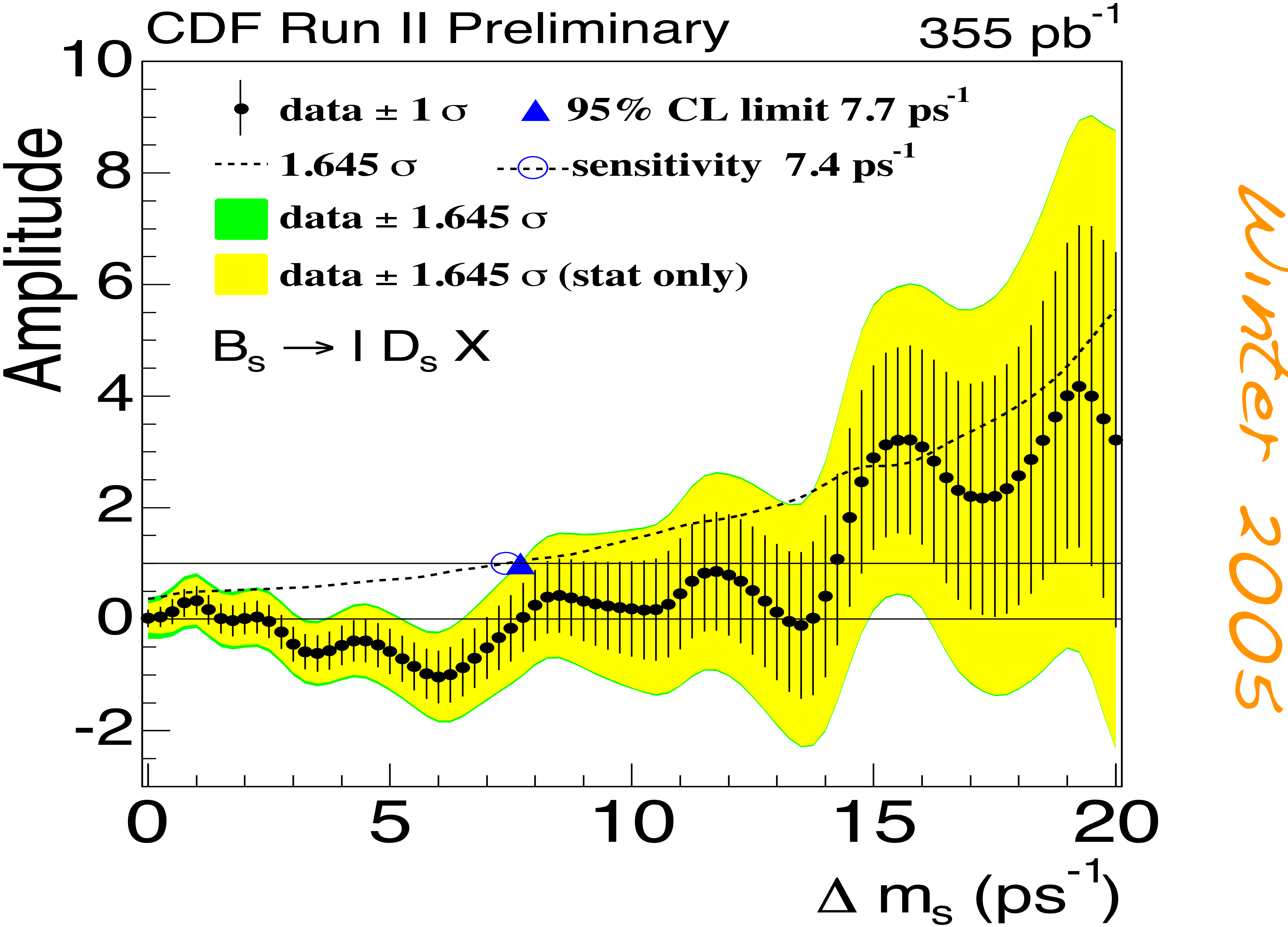
- produce&collect Bs mesons
- reconstruct their decay
- measure flight distance
- flavor at production/decay times



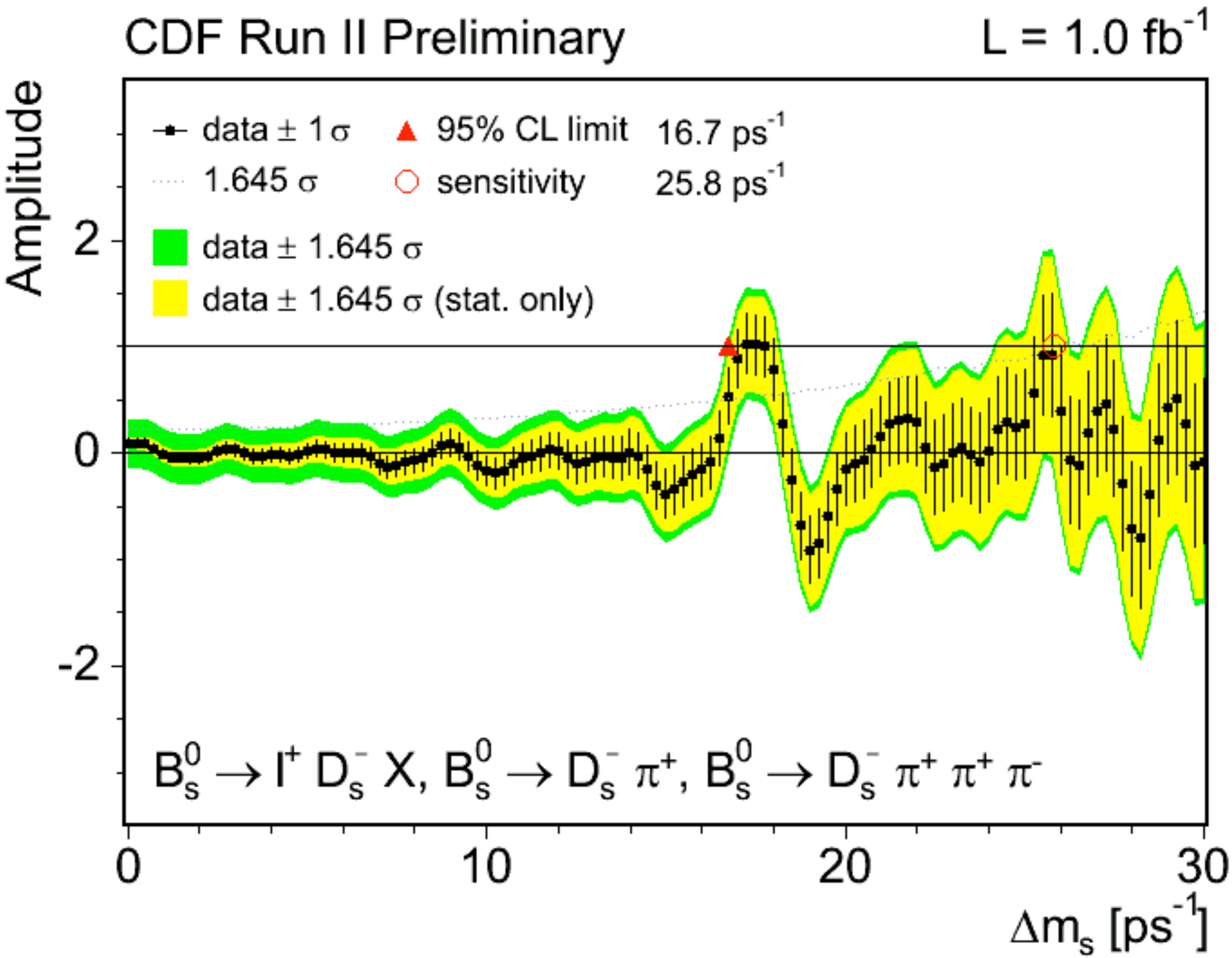
CDF Run II Preliminary
L = 1.0 fb^{-1}
Amplitude
1.5
1
0.5
0
-0.5
-1
-1.5
0
1
2
3
4
5
Oscillation frequency (trillion Hertz)



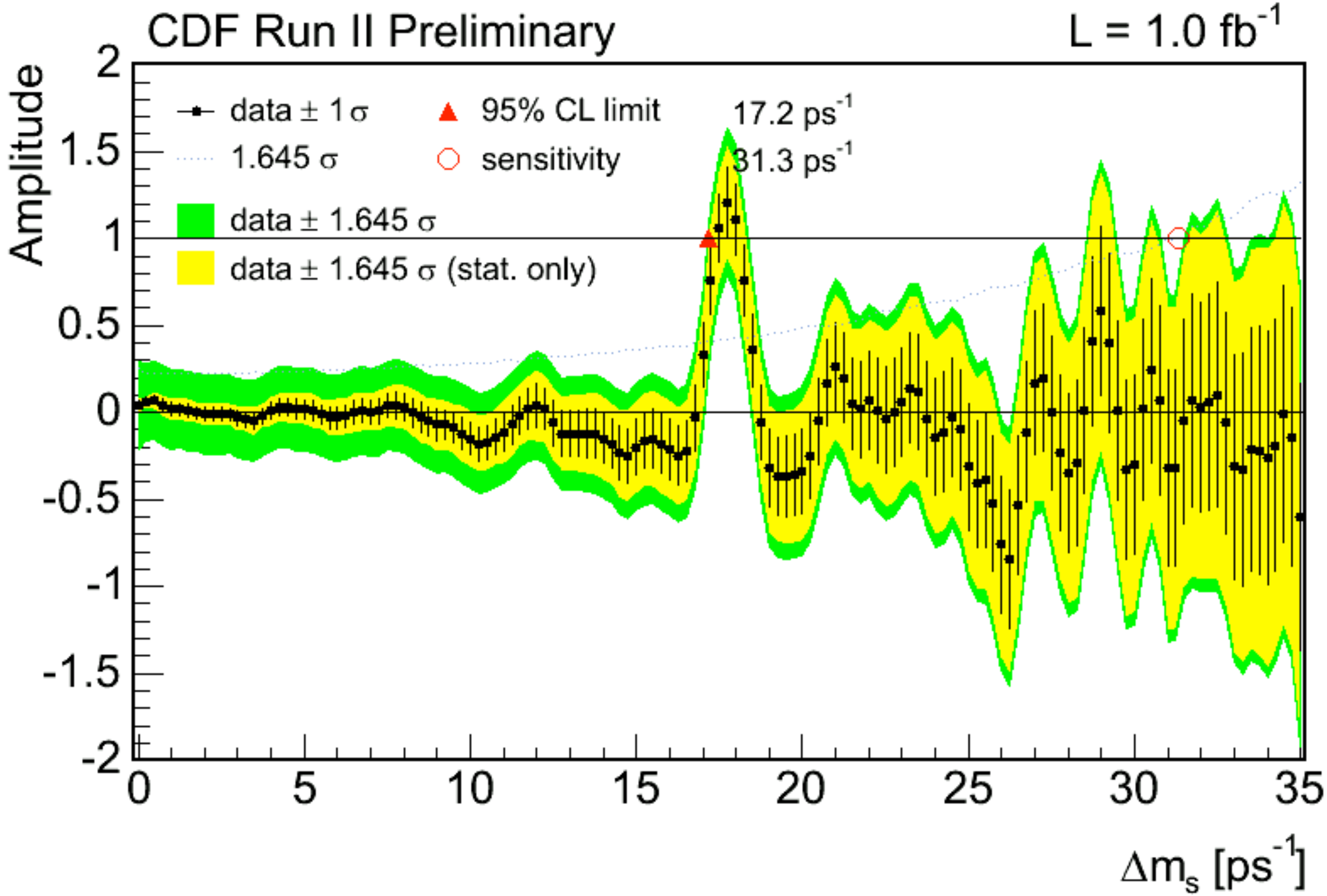
CDF Run II Preliminary
L ≈ 355 pb-1
data ± 1σ
95% CL limit 0.0 ps-1
1.645 σ
sensitivity 0.4 ps-1
data ± 1.645 σ
data ± 1.645 σ (stat. only)
Hadronic
Amplitude
Δms [ps-1]
Winter 2005



CDF Run II Preliminary
355 pb^{-1}
data ± 1 σ
95% CL limit 7.7 ps^{-1}
1.645 σ
sensitivity 7.4 ps^{-1}
data ± 1.645 σ
data ± 1.645 σ (stat only)
$B_s \rightarrow l\ D_s\ X$
Amplitude
Δm_s (ps^{-1})
10
8
6
4
2
0
-2
0
5
10
15
20
Winter 2005

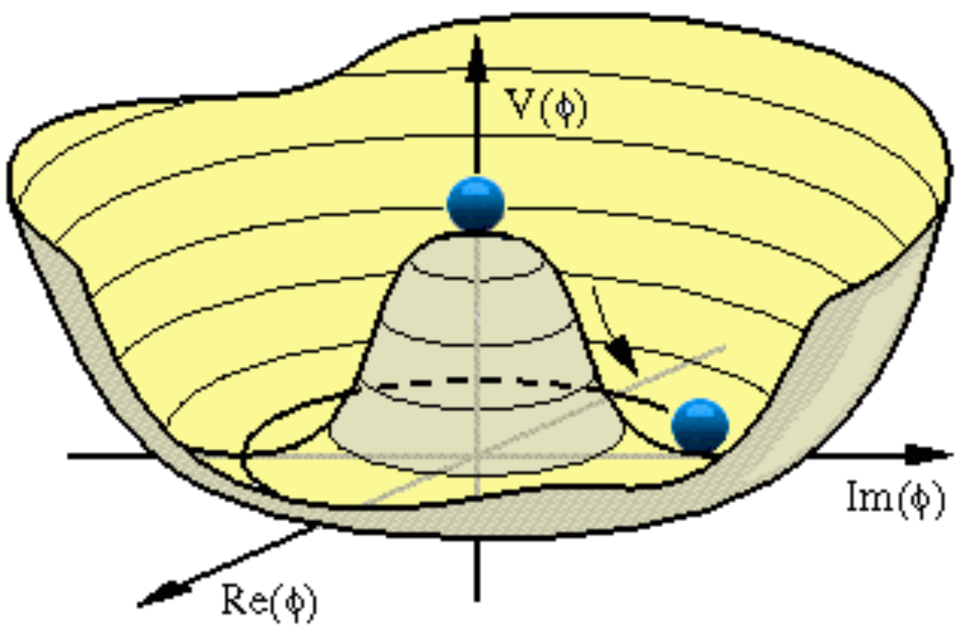

CDF Run II Preliminary
L = 1.0 fb^{-1}
Amplitude
data ± 1σ
95% CL limit 16.7 ps^{-1}
1.645 σ
sensitivity 25.8 ps^{-1}
data ± 1.645 σ
data ± 1.645 σ (stat. only)
2
0
-2
$B_s^0 \to l^+ D_s^- X$, $B_s^0 \to D_s^- \pi^+$, $B_s^0 \to D_s^- \pi^+ \pi^+ \pi^-$
0
10
20
30
Δm_s [ps^{-1}]

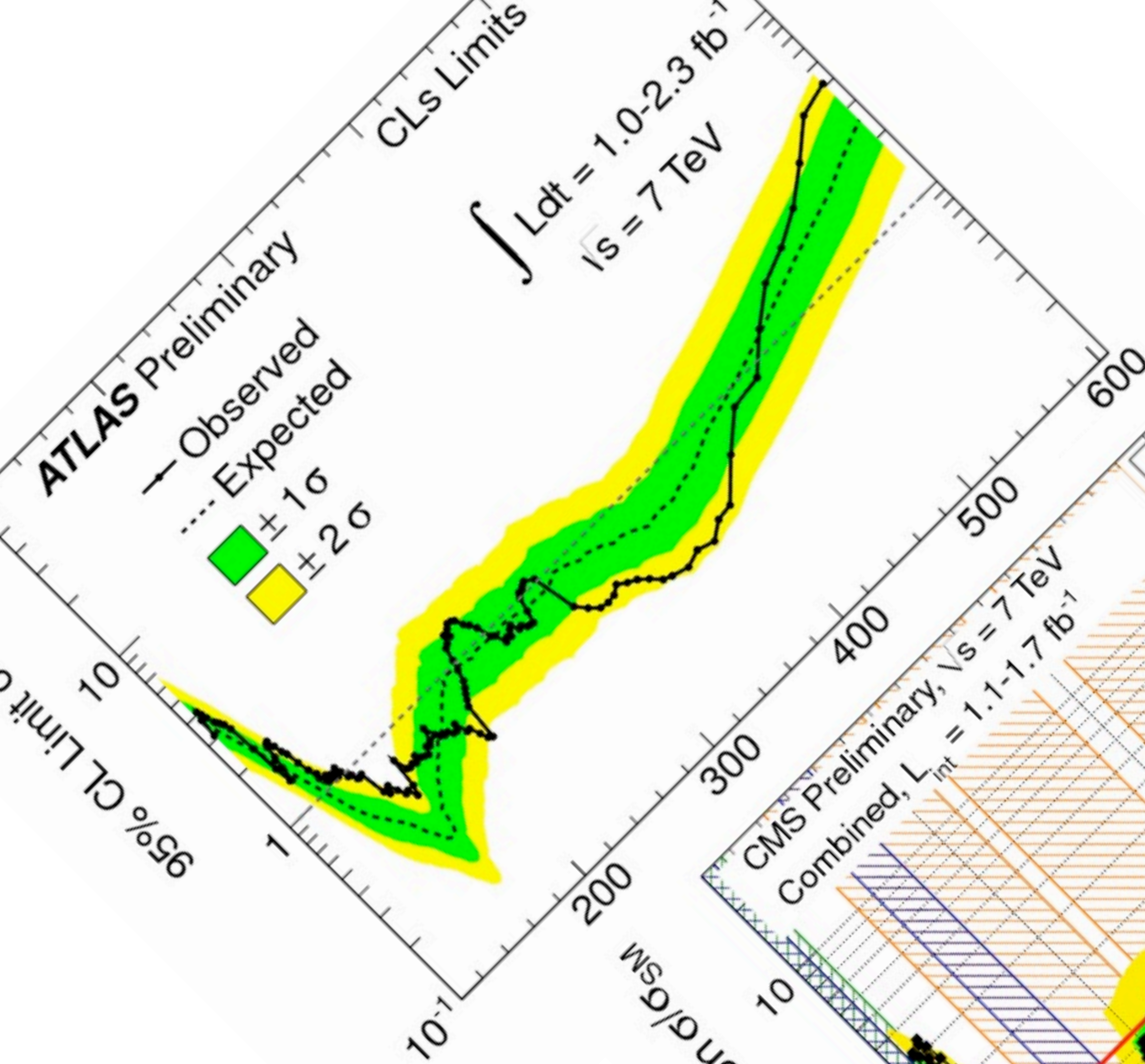
Winter 2006

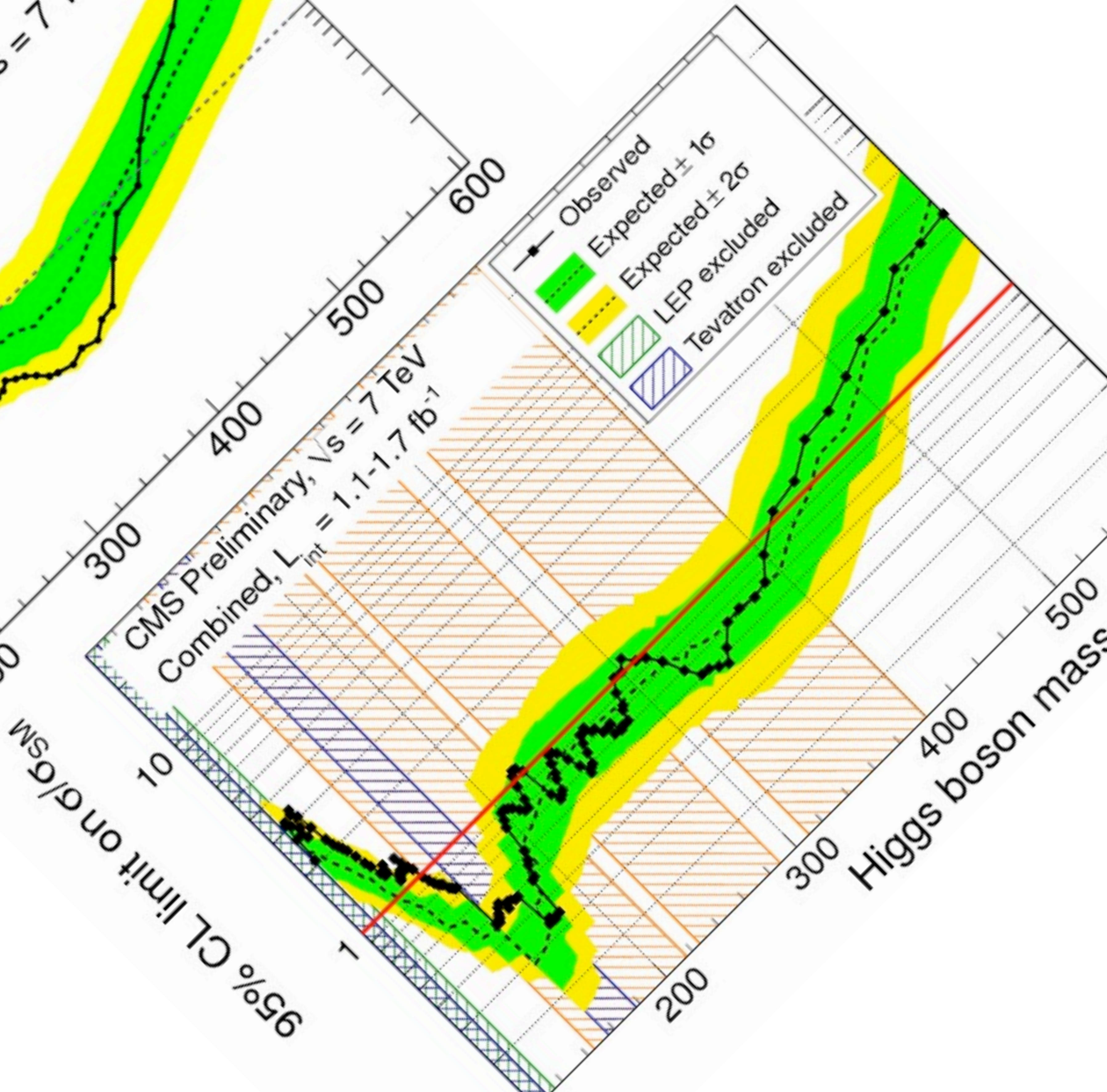

CDF Run II Preliminary
L = 1.0 fb^{-1}
Amplitude
data ± 1σ
1.645 σ
data ± 1.645 σ
data ± 1.645 σ (stat. only)
95% CL limit
17.2 ps^{-1}
sensitivity
31.3 ps^{-1}
Δm_s [ps^{-1}]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
5
10
15
20
25
30
35

Fall 2006

comparison with the current search for the Higgs boson




CLs Limits
∫ Ldt = 1.0-2.3 fb-1
√s = 7 TeV
ATLAS Preliminary
Observed
Expected
± 1σ
± 2σ
95% CL Limit o
10-1
1
10
200
300
400
500
600


CMS Preliminary, √s = 7 TeV
Combined, L_int = 1.1-1.7 fb-1
Observed
Expected ± 1σ
Expected ± 2σ
LEP excluded
Tevatron excluded
95% CL limit on σ/σSM
Higgs boson mass
1
10
200
300
400
500

resemblances

- flagship searches
- benefit from highest energies
- long preceeding search attempts
- too high frequency / too high mass: difficult to accommodate, given constraints from global fit data/ theory
- combine multiple, complementing channels (optimize sensitivity)
- search for expected phenomena
- measurement within experimental reach (w/ reasonable expectations)

unlikeness

- direct search (for a central piece of the SM) vs indirect search (BSM)
- Higgs and LHC highly popular, inside and outside physics community
- Higgs drove detector design
- Higgs granted to be settled at LHC (discovered or excluded) soon; observation of a higher mixing frequency could have taken longer
- Bs compatible with SM, while Higgs ⁉
- Bs mixing observation took 5 years, after the start of data taking; Higgs took ⁉ years ☺